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13. ABSTRACT *(Maximum 200 words)*
This project has attempted to elucidate the representations and processes involved in implicit and explicit memory for novel visual objects. Experiments have been conducted that 1) clarify the effects of structural and functional encoding manipulations on priming and explicit memory, 2) track the properties of the observed priming effects over time and repetition, 3) specify the nature of the structural representation that underlies priming effects on the objects decision task, 4) extend findings on priming of novel objects to new materials and paradigms, and 5) elucidate the extent to which implicit memory for novel objects is spared in subject populations with explicit memory deficits. We summarize the procedures and results from each of these five lines of research.

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Abstract

This project has attempted to elucidate the representations and processes involved in implicit and explicit memory for novel visual objects. Experiments have been conducted that 1) clarify the effects of structural and functional encoding manipulations on priming and explicit memory, 2) track the properties of the observed priming effects over time and repetition, 3) specify the nature of the structural representation that underlies priming effects on the object decision task, 4) extend findings on priming of novel objects to new materials and paradigms, and 5) elucidate the extent to which implicit memory for novel objects is spared in subject populations with explicit memory deficits. We summarize the procedures and results from each of these five lines of research.

Status of the Research

The major research tool developed for this project was an object decision test that allows the examination of implicit memory for novel objects. Implicit memory is observed in test situations in which previous experiences influence task performance, even though subjects are not required to, and may be unable to, consciously or explicitly recollect those experiences. Facilitation of implicit test performance is often referred to as a priming effect, i.e., subjects are faster or more accurate to identify, or make decisions about, previously studied items compared to nonstudied items that provide an estimate of baseline performance. Unless otherwise stated, priming or implicit memory in the present experiments was assessed with a possible/impossible decision task in which previously studied and nonstudied possible and impossible objects were flashed briefly (i.e., 50 msec) and subjects decided whether each object is possible or impossible. Explicit memory was assessed with a yes/no recognition task. Our previous research has revealed that object decision priming a) requires structural encoding of objects, b) is observed for possible but not impossible objects, c) can be dissociated experimentally from explicit memory by manipulating depth of encoding, d) is robust across study-to-test changes in size and reflection of objects, and e) is preserved in amnesic patients who have serious explicit memory deficits. These findings have led us to hypothesize that priming on the object decision task reflects the operation of a presemantic structural decription system that computes size-and reflection-invariant representations and can function independently of an episodic system that supports explicit memory. The various lines of research carried out for this project were designed with a view toward exploring and testing these ideas.

1. Structural vs. functional encoding manipulations

One major series of studies compared the effects of encoding structural and functional aspects of visual objects on object decision and recognition performance. An initial experiment indicated that an encoding task that required subjects to think about an object's functional properties (judging whether it best used as a tool or for support) produced higher recognition than did an encoding task that required subjects to think about an object's structural properties (i.e, whether it is facing primarily to the left or to the right). In contrast, however, the magnitude of priming following the two encoding tasks was virtually identical. However, overall levels of performance were rather high in this experiment, with object decision accuracy for studied items in the range of 80% correct, thus raising the possibility that ceiling effects might be obscuring real differences between the encoding tasks. A follow-up experiment produced lower overall levels of object decision performance by lowering exposure rate on the object decision test from 100 msec to 50 msec. Neverthless, the magnitude of priming following the structural and functional encoding tasks was once again nearly identical -- even though functional encoding yielded much higher levels of recognition memory than did structural encoding.

Further experiments examined exactly what kinds of functional encoding tasks yield significant priming on the object decision test. We have argued that priming is attributable solely to the encoding of global information about the three-dimensional structure of novel objects in a presemantic structural description system. Why, then, does making a judgment about an object's function produce any priming at all? One possibility is that priming is observed following a functional encoding task only when the putative function that an object might perform is directly constrained by the structure; in the tool/support judgment task, for example, the structure of an object determines whether it could best be used as a tool or for support. Is such a constraint between structure and function necessary for a functional encoding task to produce priming? According to our view, priming is observed following a structural encoding task because making a functional judgment necessarily involves an analysis of structure. Thus, we would contend that any judgment about a novel object's potential function must depend on structural analysis, and that the exact relation or mapping between structure and function should not be important. Thus, priming should occur following functional encoding tasks even when structure does not directly constrain function. To test this idea, we developed encoding tasks in which subjects made judgments about the kinds of sounds that they thought that novel objects might make -- judgments in which structure has little to do with the putative function. Consistent with our prediction, we found that priming was observed even following various functional encoding tasks in which subjects made judgments about whether novel objects would be more likely to make loud or soft sounds.

Additional experiments examined whether combining structural and functional encoding tasks would produce more priming than either structural or functional encoding tasks alone. If the priming that was observed following the functional encoding task is attributable solely to structural analyses that are carried out in the course of making a functional judgment, then priming should not differ among the various conditions. On the other hand, if priming in the functional condition is based on a different type of information than priming in the structural condition, then performing both structural and functional encoding tasks should enhance priming. In two experiments, we found equivalent levels of priming across the various encoding conditions, consistent with the idea that priming in the functional condition is attributable to encoding of structural information, which may be an obligatory part of the functional encoding task. Thus, the results of these experiments are generally supportive of the structural description system hypothesis.

2. Effects of Delay and Repetition

While it is clear that robust priming of novel objects on the possible/impossible decision task can be observed following structural encoding tasks, not much is known about the durability of the observed effects. All of our previous experiments were conducted with relatively brief study-to-test retention intervals of approximately two minutes, so we do not know whether priming is a transient or persistent phenomenon. Because relative degree of persistence over time is such an important feature of any memory phenomenon, we decided to carry out a large parametric study that systematically explored the time course of object decision priming.

We crossed the retention interval manipulation with an orthogonal manipulation of number of study list repetitions. In earlier research, we found that the magnitude of priming for possible objects was about the same following one and four repetitions, even though explicit memory was increased substantially by this manipulation. In addition, we failed to observe priming of impossible objects following both one and four study list repetitions. The fact that priming of possible objects was not enhanced by repetition has potentially important theoretical implications for understanding the nature of the mechanism that produces the phenomenon. However, before accepting the null hypothesis that repetition has no effect on magnitude of object decision priming, it seemed prudent to gather additional data. The design of the experiment was a between-subjects factorial in which three levels of retention interval (1 min, 1 day, 1 week) were crossed with four levels of repetition (1, 2, 4, 6), thus yielding 12 independent groups of subjects (20 subjects per group). Consistent with previous results, there was no evidence for priming of impossible objects in any experimental condition. The data for possible objects revealed an interaction between retention interval and number of repetitions. With more than one repetition of an object during the study task (i.e., the 2, 4, and 6 repetition conditions), retention interval had no influence on object decision performance; priming was significant at all delays, and the magnitude of the effect did not differ as a function of delay. With only a single study list presentation of an object, however, there was a main effect of delay, and priming was not significant at the 1 week retention interval. Thus, while object decision priming can persist over lengthy delays, it requires more than a single study list exposure in order to do so. And, conversely, it appears that repetition can have an influence on priming, but the effect is only revealed at long delays; priming of possible objects at the 1 min retention interval was virtually identical across the various levels of repetition.

3. Nature of structural representations that support priming

We have conducted a number of experiments that explore the nature of the representations that support object decision priming by using the study-to-test attribute change paradigm, in which we vary specific features of target objects between study and test. The logic behind this experimental paradigm is straightforward: If transformations of specific object properties from study to test modify or reduce the magnitude of priming or recognition effects, we can conclude that the system accessed by the relevant memory task does represent information about the property that was transformed. However, if priming or recognition effects remain invariant over study-to-test changes in object attributes, than we can infer that the system accessed by the relevant memory test does not preserve information about the transformed attribute.

In one major series of experiments along these lines, we examined the effects of changing the picture plane orientation of target objects on priming and recognition. Initial experiments described in earlier progress reports indicated elimination of priming by changes in picture plane orientation using rotations of 120 deg and 240 deg. We have now completed this series of experiments. In the last experiment, using a between-groups design, objects were studied in either the "canonical" position or in a position departing 180 deg from that view. At testing, objects were presented in either the studied or the 180-deg rotated position (within-subjects), and different groups engaged in either the implicit object decision test or explicit yes/no recognition. We obtained results entirely consistent with our earlier findings: Both priming and recognition were dramatically reduced as a result of the transformation of rotation in the picture plane. This finding provides further support for the claim that structural representations of 3D objects are axis-based and are computed relative to a perceptual frame of reference. Further evaluation of this idea has required the development of sets of stimuli different from the possible and impossible objects (see below).

In a final experiment examining study-to-test changes in object attributes, we manipulated the relationship between the color of objects presented for study and at test. Three different colors (red, cyan, and gold) that filled in or "washed" over the entire area of each object, but provided no information concerning depth, were used. Different groups of subjects studied all objects in one color only, then were tested with objects in any of the three colors. As usual, different groups of subjects engaged in the object decision and recognition memory tests. Results indicated that color transformation produces no statistically significant effects in the magnitude of either object decision priming or explicit recognition. While the former result was predicted, the latter result is mildly surprising. Apparently, color -- in the case of these unfamiliar objects -- is not a characteristic that produces as distinctive memory encodings as properties like size and orientation.

Results from the entire set of experiments using study-to-test attribute changes that have been undertaken during the course of this project are summarized in Figures 1 (object decision) and 2 (recognition), shown separately for each study-to-test transformation but averaged over possible and impossible object types. This line of research has been extremely productive; it has enriched our understanding of the structural and episodic systems of objects representation both descriptively and theoretically. At the descriptive level, structural representations appear insensitive to transformations of size, reflection, and color, but are clearly affected by rotation in the plane of the picture. Episodic representations are affected by all study-to-test transformations, except for manipulations of object color. Theoretically, these results suggest that structural representations of objects are computed pre-semantically -- before analyses of meaning, naming, and familiarity occur -- and that they are abstract and specialized for coding perceptual invariance. The effect of picture-plane rotation suggests, further, that structural representations code an object's major axes of elongation and symmetry and, possibly, the relation of component parts to those axes. Episodic representations of objects serve to encode unique object identity in memory. Consequently, types of visual information that enhance an object's distinctiveness (e.g., size, parity, orientation), as well as semantic and functional information about an object, are preserved in the episodic system.

4. Priming and recognition of depth-cued, 3D objects

A significant accomplishment during the project period has been the development and use of a new set of stimuli and a new implicit memory task, in an effort to expand our understanding of how visual objects are represented in and retrieved from memory. The objects, developed on a Silicon Graphics IRIS computer (supplied to L. A. Cooper by Columbia University), are similar to the "possible" structures used in our other lines of work, but rendered as more realistic, depth-cued, solid 3D models. The implicit memory task requires subjects to determine whether briefly-presented objects are symmetric or asymmetric in structure. We have generated well over 100 such objects, and 72 of them (36 symmetric, 36 asymmetric about one or more plane) satisfy the following criteria for use in experiments: The objects (a) are identified correctly as symmetric or asymmetric by more than 90% of subjects under conditions of unlimited viewing, and (b) yield accuracy in the range of 60-80% under conditions of brief (50 ms) exposure. Figure 3 gives examples of symmetric and asymmetric objects (whose 3D quality is greatly degraded by the combination of laser printing and xeroxing). Considerable time and effort has been devoted to developing this object set and piloting the new implicit memory task; however, we felt that it was important for a number of reasons. First, it seems theoretically crucial to assess whether our results obtained with possible and impossible objects generalize beyond the potential peculiarities of object "impossibility". Second, since our goal is to understand how objects in the perceptual world are represented in memory, it seems desirable to introduce sources of real-world information (e.g., texture, shading) that cannot be rendered in line drawings of either unfamiliar or familiar objects. Third, certain object transformations that play a major role in our theoretical account (e.g., rotation of objects in depth) cannot be accomplished with line drawings of impossible objects, because such objects cannot be modeled as 3D structures. Already, the effort undertaken in developing the object set has produced tangible results along several lines.

We have completed a series of experiments with the novel depth-cued objects in which conditions of encoding were manipulated. Using our standard structural encoding condition (judging whether objects are facing to the left or to the right), substantial priming on the symmetry decision task was obtain for symmetric, but not for asymmetric objects. Figure 4 summarizes the results on both implicit (symmetry decision) and explicit (recognition) test tasks. The occurrence of priming of symmetry decisions is important, because it extends the generality of our results with possible/impossible objects, and indicates that both the depth-cued, 3D stimuli and the new implicit memory task are suitable for use in future experiments. The failure to obtain priming of "asymmetric" responses is reminiscent of the consistent absence of priming of impossible objects. This superficial similarity leads naturally to the question of whether the two outcomes are rooted in similar computational constraints on the structural description system. We think not, for several reasons. First, there is no principled reason for postulating that the structural description system should be unable to compute global representations of the relations among components of asymmetric 3D objects. Second, there are two highly consistent features of the data from the present experiment that were not found in the studies using impossible objects. These are the significantly higher baseline rates of performance on asymmetric, compared with symmetric, objects on the implicit test task, as well as their correspondingly high level of explicit recognition (cf., Figure 4).

Our current hypothesis is that the task of judging asymmetry, as opposed to asymmetric object structure per se, is responsible for the absence of priming. Note that this judgment can be made using either or both of two sources of information -- a global structural representation of an object, or a representation of one or more features that distinguish the shapes of the two sides of the object separated by a major axis. The fact that a global structural representation need not be used may account for the absence of priming of "asymmetric" responses; the availability of multiple sources of information for the response may account for its overall superiority. We are currently testing this hypothesis directly in an experiment using possible and impossible objects, and requiring either "possible/impossible" or "symmetric/asymmetric" responses. Our response-based hypothesis concerning the absence of priming of asymmetric objects predicts that possible, asymmetric objects will exhibit priming under conditions requiring a possible/impossible decision, but not under conditions requiring a symmetric/asymmetric decision.

We have also completed several experiments attempting to produce dissociations between performance on implicit and explicit memory tasks by manipulating encoding requirements, as in our earlier work. In one, we tried to direct attention to local aspects of the depth-cued 3D objects by having subjects determine during study whether more of each object's edges were oriented horizontally or vertically, as opposed to diagonally. By analogy with our previous results, it might be expected that priming of symmetric objects would not be obtained in this situation, because attention to surface orientations could preclude developing a global representation of the objects' 3D structures. However, we were skeptical that subjects could suppress the tendency to encode the compelling 3D structure of these depth-cued objects, even when required to make edge-based decisions as a study task. In a second experiment, we asked subjects to provide meaningful elaborations for each studied object by naming something familiar that the object reminded them of most strongly. For this study condition, we expected a substantial increase in explicit recognition memory, because the encoding requirement should serve to enhance an object's distinctiveness in episodic memory. We also predicted robust priming for symmetric objects; this is because subjects would be expected to associate the unfamiliar depth-cued structures with meaningful 3D objects.

Priming and recognition results from these local and elaborative encoding experiments, averaged over symmetric and asymmetric objects, are shown along with results from the structural study task in Figure 5. The data generally confirm our predictions; recognition was significantly enhanced by elaboration instructions, and all three encoding task produced substantial priming on the symmetry decision task. The presence of priming in the local encoding experiment raises the question of whether any conditions could be found in which priming would be absent for the depth-cued 3D objects. Our theoretical analysis holds that the structural descriptions supporting priming embody information about the global 3D relations among an object's parts. Thus, any condition of encoding that made the representation of specifically 3D structure unlikely or impossible should fail to yield priming on an appropriate implicit memory task. To evaluate this idea, we created such conditions by using as encoding displays silhouettes or shadows of the depth-cued objects (see Figure 6), and using the depth-cued objects for subsequent symmetry decision or recognition testing. Under these conditions, essentially no priming was exhibited on the symmetry decision task. This finding supports our contention that structural representations contain abstract information about the global 3D relations among parts of an object.

We have also used the depth-cued objects to assess study-to-test transformations that could not be accomplished with the stimulus set containing impossible structures. In particular, we have completed an experiment in which objects were studied in a "canonical" position, and then tested either in the same position or in orientations departing by 30 or by 90 degrees of rotation about the vertical axis in depth. Priming was observed for both canonical test positions and for the test positions rotated in depth. This finding is consistent with the idea that structural descriptions code an object's major axis with respect to a perceptual frame of reference. Note that such a structural specification should not be disrupted by a rotation about the vertical axis in depth, as it is by a rotation in the plane of the picture. We are just now completing a series of experiments with the depth-cued objects, using the study-to-test transformation of rotation in the picture plane. In our initial experiment, results were somewhat inconclusive owing to inexplicable perturbations in baseline levels of performance. In the second experiment, subjects studied the objects in either the canonical position or in a position departing by 180 deg from the canonical view. Test positions included both the canonical view and the 180 deg picture plane rotation. Although the data are not fully analyzed, analysis of one subcondition shows priming when studied and tested orientations are the same, but reduced priming when the positions differ by a 180 deg rotation in the plane. This is just the outcome that we should expect under the axis-based account of structural description representations.

5. Studies of memory-impaired populations

All of the foregoing studies involved college students populations. However, we have also investigated implicit and explicit memory for novel objects in memory-impaired populations. Two initial experiments with elderly adults examined priming and explicit memory following the left/right encoding task, under conditions in which the physical features of the target objects were identical at study and test. Both experiments showed intact object decision priming in the elderly despite impaired recognition memory. However, these experiments also revealed that elderly adults performed quite poorly on the object decision task despite showing a normal priming effect -- that is, their baseline level of object decision accuracy was lower than that of young control subjects and not significantly different from chance. These observations raise the possibility that the structural description system is not entirely normal in elderly adults, although it can support robust priming.

To investigate the matter further, we asked whether elderly adults would show size invariant priming, as we have observed previously in young subjects. An initial experiment yielded an unexpected, but interesting, outcome. Following a study trial in which they viewed large objects (that subtended a visual angle of about 18 deg), elderly adults showed similar amounts of priming when tested with large objects or with small objects (that subtended a visual angle of 6 deg). Thus, they exhibited size-invariant priming. However, when the elderly subjects studied small objects, they showed no priming when tested with either small or large objects. These observations suggest that the elderly had difficulties in extracting three-dimensional structural information from small objects.

A follow-up experiment attempted to determine the boundary conditions of the phenomenon by using a size intermediate between the two sizes that had been used in the initial experiments (i.e., the objects subtended about 12 deg of visual angle). We ran each of the four experimental conditions that result from the orthogonal combination of the large and small sizes in a between-subjects design with 20 subjects per group. In contrast to the initial experiment, elderly adults now showed significant priming following study of the small (12 deg of visual angle) objects, both when they were tested with small objects and large objects. Surprisingly, however, the elderly showed quite weak priming following study of the large objects, in contrast to the results of the earlier experiment. Careful inspection of the data, however, revealed that this outcome was largely attributable to a small number of subjects who showed highly unusual patterns of data.

To obtain closure on the matter, we conducted a follow-up experiment in which we ran all conditions again, but doubled the number of subjects per group (n=40) in order to obtain reliable data. Under these conditions, elderly adults showed significant priming in all experimental conditions, and no differences among conditions. Thus, it seems safe to conclude that the elderly exhibit reliable size invariance in object decision priming, and that they can show priming after studying relatively small objects (i.e., those that subtend 12 deg of visual). We continue to conduct experiments to clarify why the elderly do not show significant priming following the study of smaller objects.

We have also investigated object decision priming in amnesic patients. A previous experiment had shown intact priming on the possible/impossible object decision task in patients with organic memory disorders. The newer experiment was conducted with a group of 12 amnesic patients from the Boston VA Hospital. The experiment is similar to the above-described experiment with elderly adults in that it examined <u>properties</u> of priming in amnesics by assessing whether object decision *priming in amnescis shows size invariance. Because of our findings with the* elderly, we used only large objects for the study task (many of the amnesics are elderly), and then presented all objects in the small size for object decision and recognition. Results indicated that the amnesic patients showed normal priming across this size change manipulation despite impaired levels of recognition performance. Thus, it looks as though size invariant priming can be observed even in patients with damage to the brain structures that support explicit remembering. These results support our hypothesis that object decision priming is mediated by a structural description system that functions independently of the episodic memory system that is damaged in amnesia and supports explicit remembering.

<u>Miscellaneous</u>

Other projects that were initiated with the support of the grant are still underway and not yet complete. One project with Dr. Stephen Kosslyn of Harvard University examines whether object decision priming is mediated primarily by the right or left hemisphere. In these studies, target drawings are presented in either the left or right visual field on the object decision test, both to normal subjects and to split-brain patients. The relevant experiments are still being conducted. Another project involves a collaboration with a neuroimaging research center headed by Dr. Eric Reiman at Good Samaritan Hospital in Phoenix, where we have completed a PET imaging study of object decision priming. Our paradigm was modified to meet the demands of the PET laboratory by carrying out pilot work in Schacter's laboratory, and the appropriately modified task was given to 16 subjects undergoing PET scans. Data are under analysis and should be available soon. We have hypothesized that regions of extrastriate cortex are critically involved in object decision priming, and are hopeful that this experiment will provide information that bears directly on this hypothesis.

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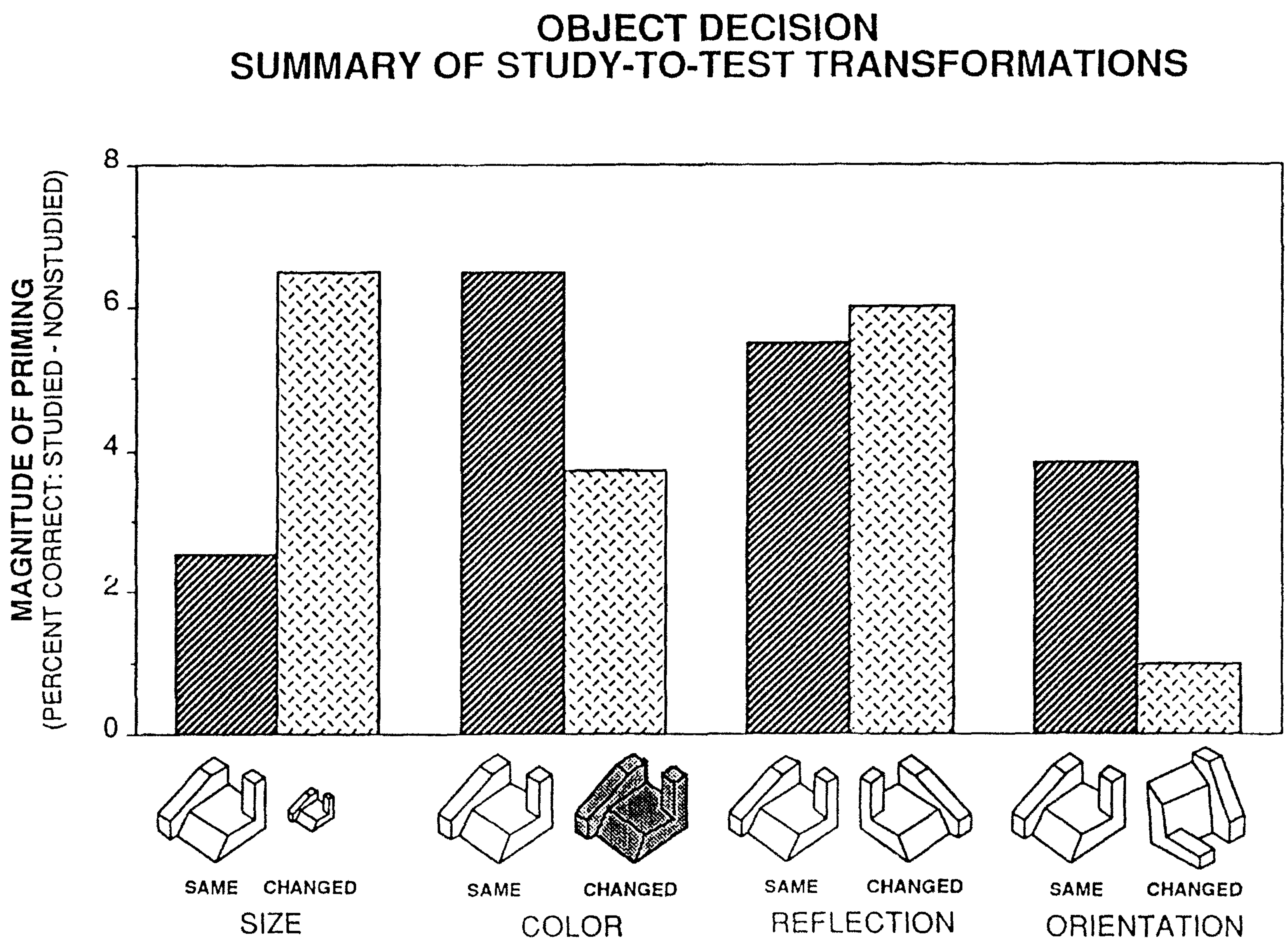

OBJECT DECISION
SUMMARY OF STUDY-TO-TEST TRANSFORMATIONS
MAGNITUDE OF PRIMING
(PERCENT CORRECT: STUDIED - NONSTUDIED)
8
6
4
2
0
SAME
CHANGED
SIZE
SAME
CHANGED
COLOR
SAME
CHANGED
REFLECTION
SAME
CHANGED
ORIENTATION

Figure 1

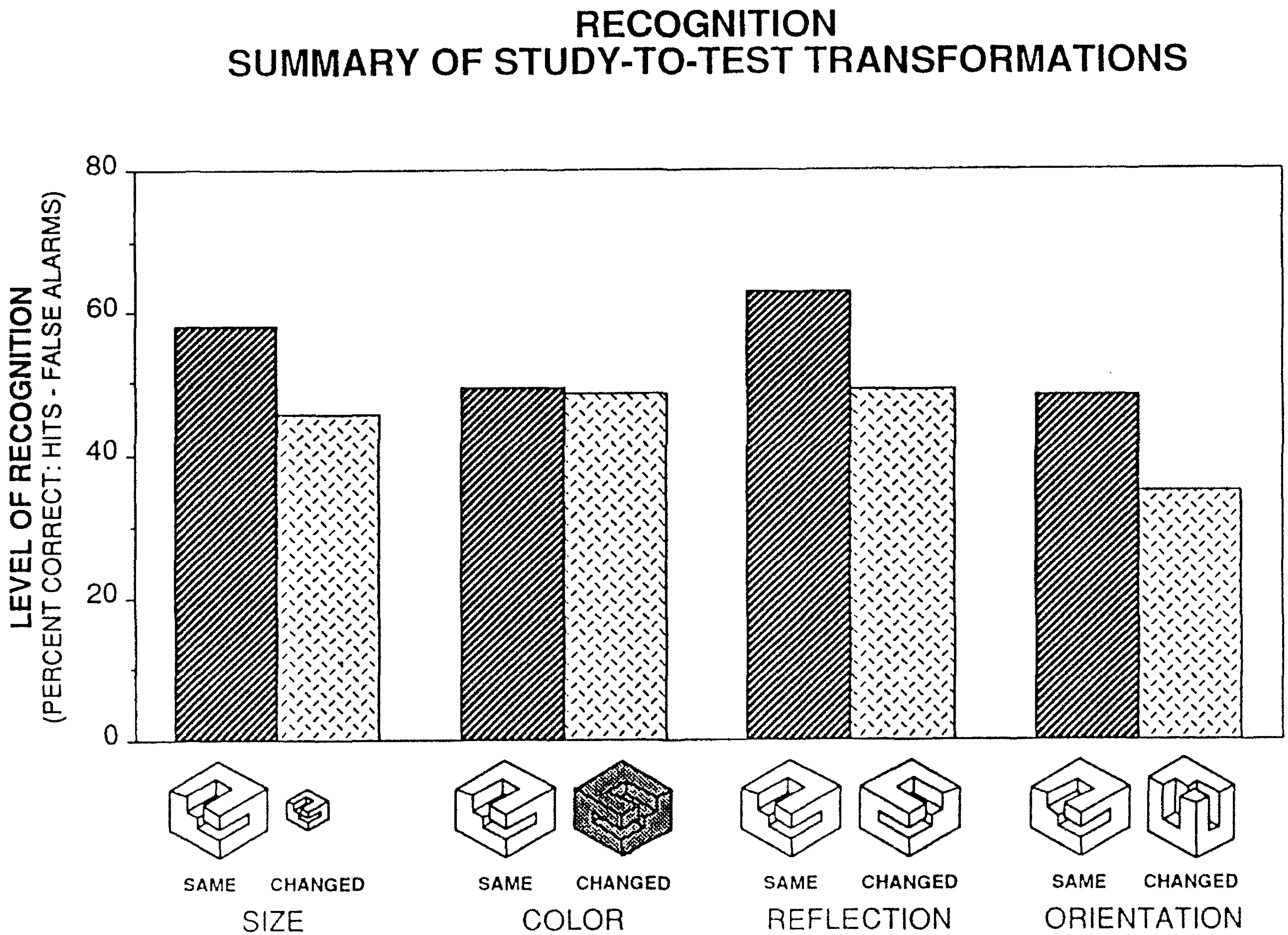
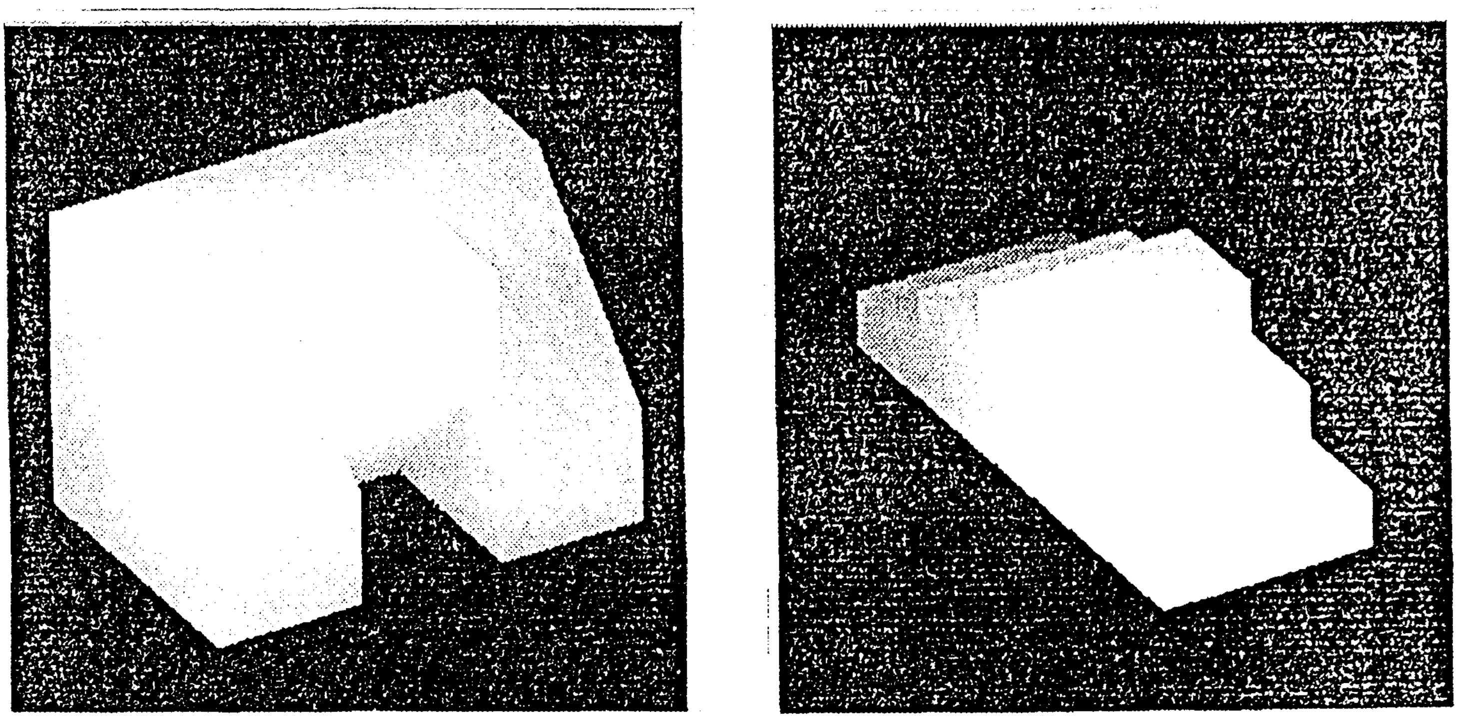

RECOGNITION
SUMMARY OF STUDY-TO-TEST TRANSFORMATIONS
LEVEL OF RECOGNITION
(PERCENT CORRECT: HITS - FALSE ALARMS)
80
60
40
20
0
SAME
CHANGED
SIZE
SAME
CHANGED
COLOR
SAME
CHANGED
REFLECTION
SAME
CHANGED
ORIENTATION

Figure 2

Figure 3



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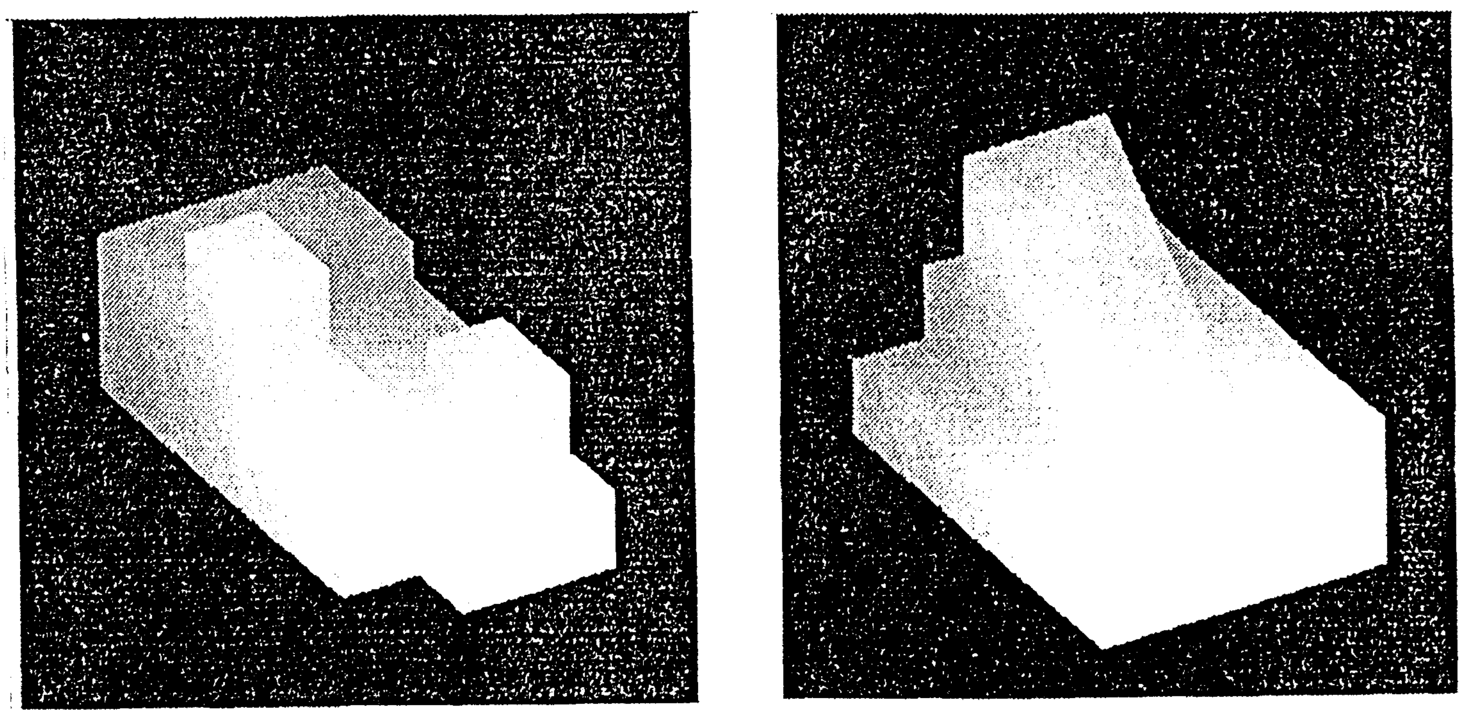


ASYMMETRIC

Figure 4

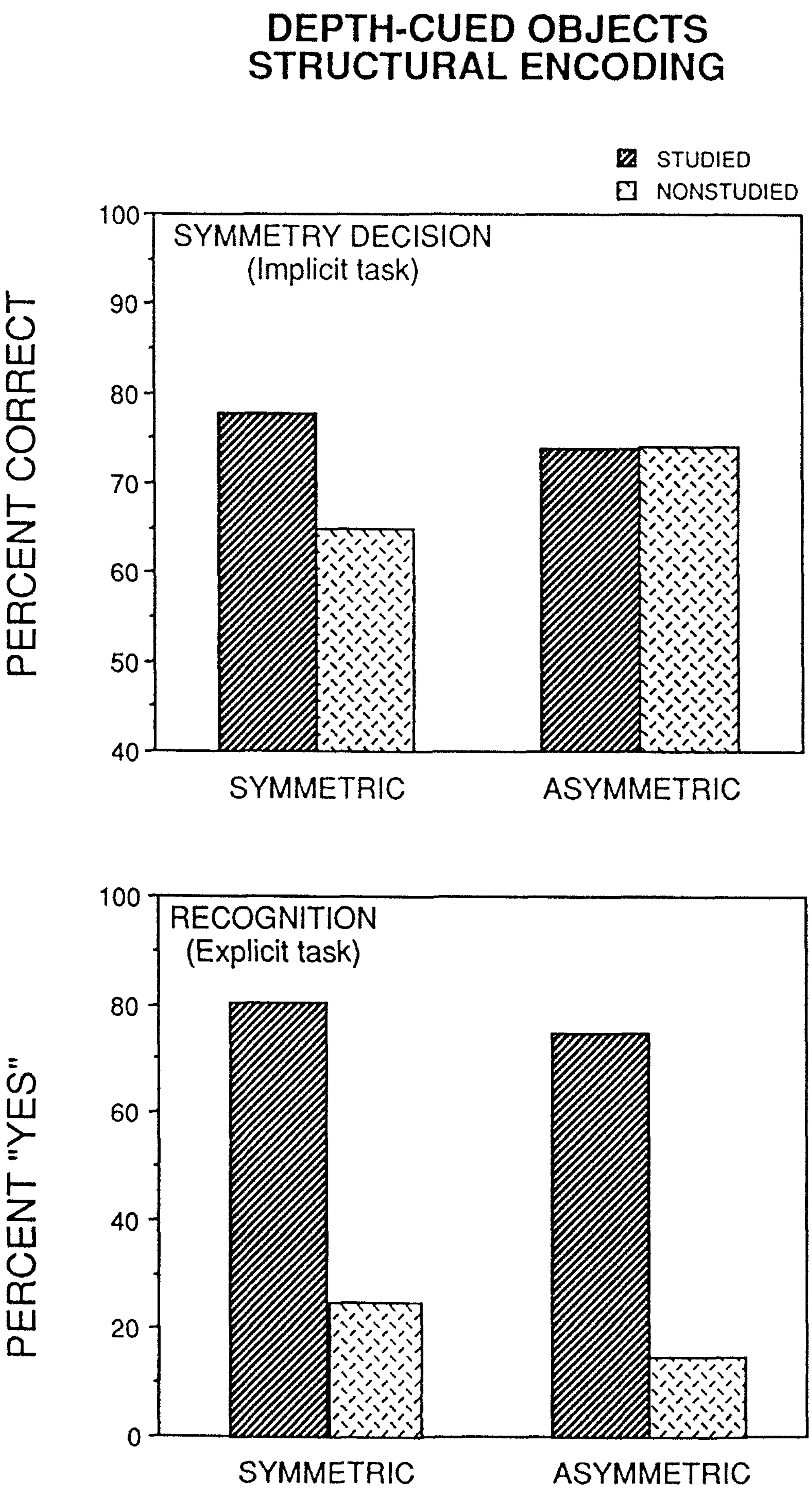

DEPTH-CUED OBJECTS
STRUCTURAL ENCODING
STUDIED
NONSTUDIED
SYMMETRY DECISION
(Implicit task)
PERCENT CORRECT
100
90
80
70
60
50
40
SYMMETRIC
ASYMMETRIC
RECOGNITION
(Explicit task)
PERCENT "YES"
100
80
60
40
20
0
SYMMETRIC
ASYMMETRIC

Figure 5

SUMMARY OF PRIMING AND RECOGNITION RESULTS 3D ENCODING MANIPULATIONS

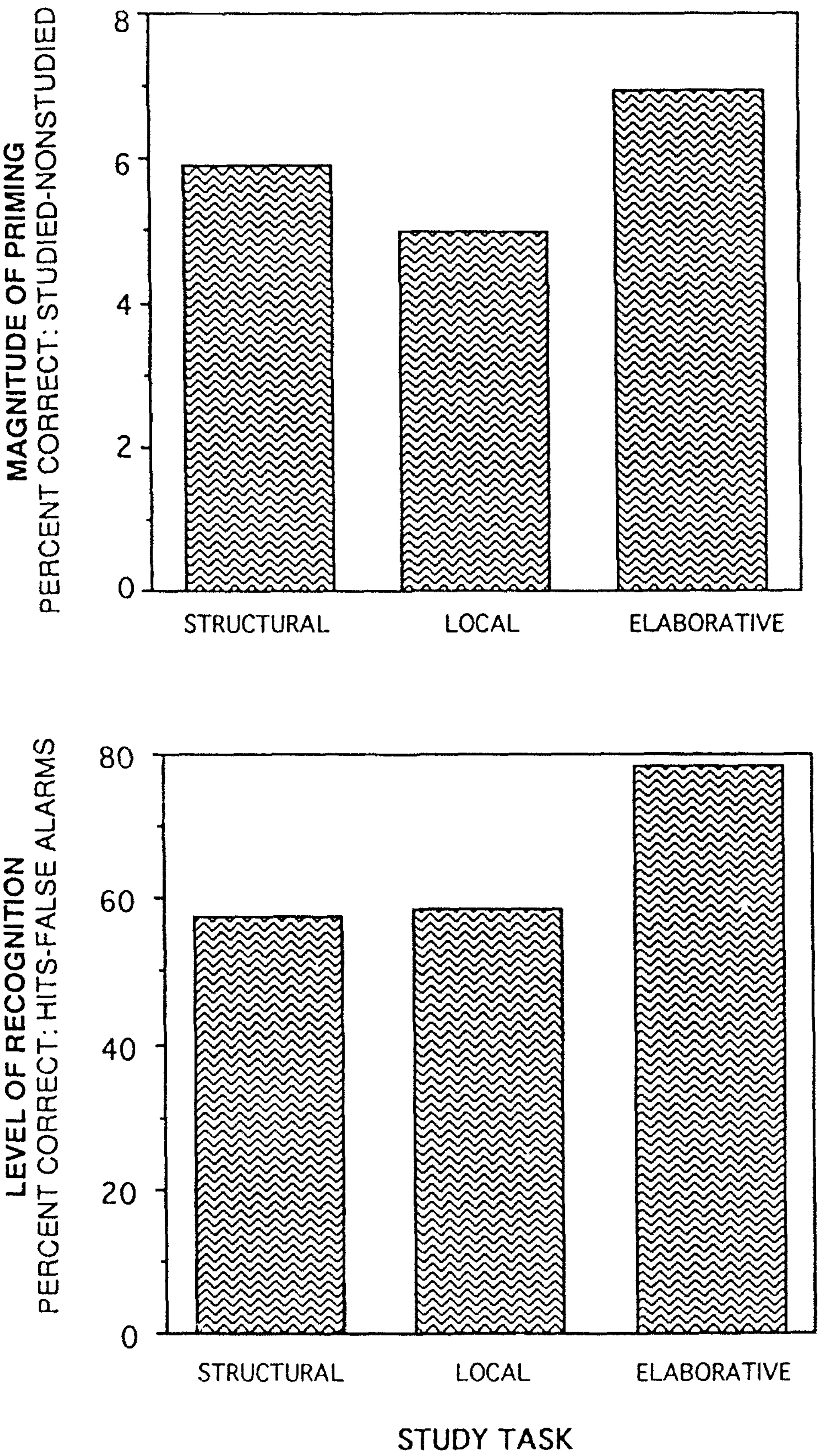
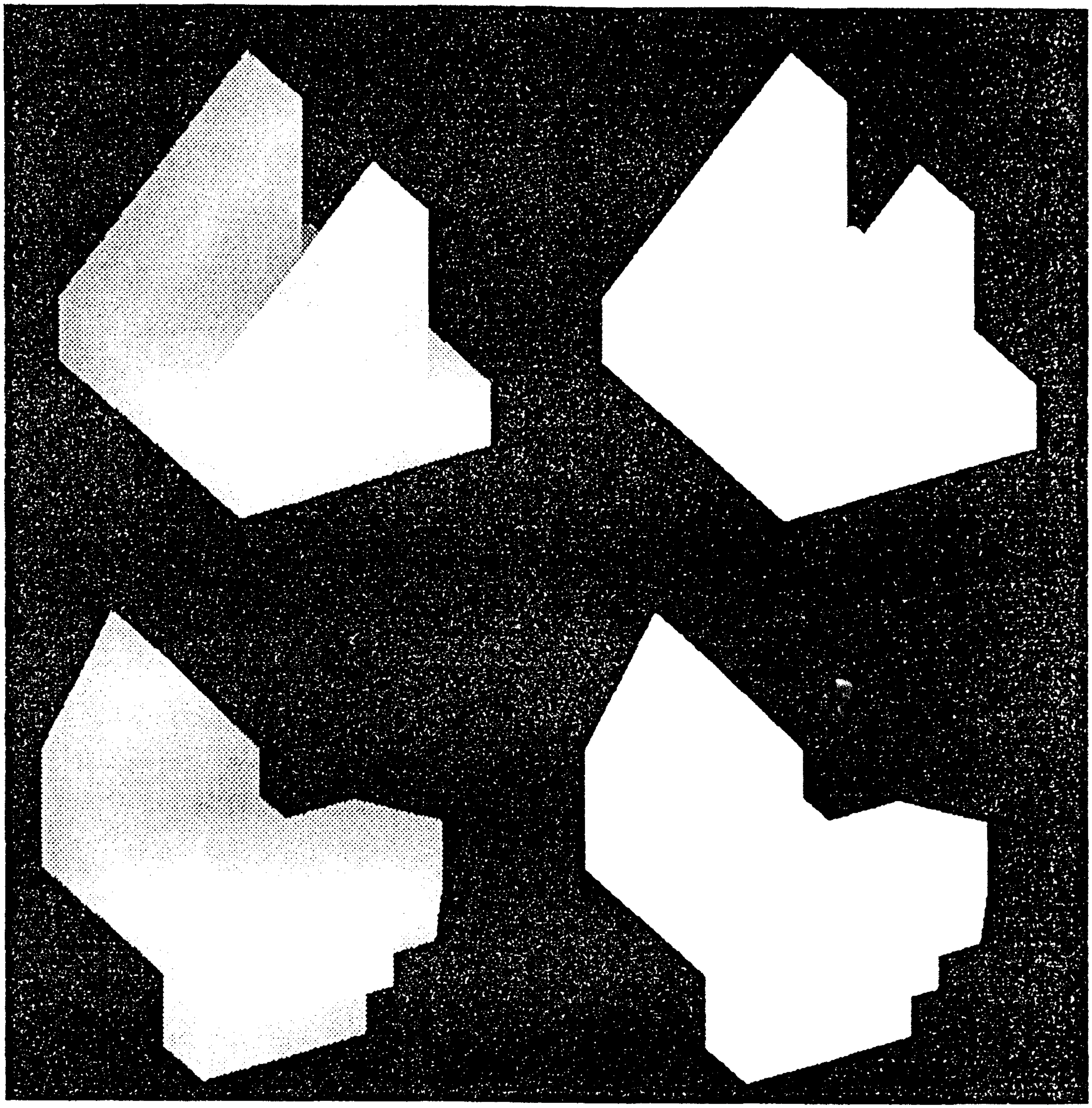


Figure 6



3D OBJECTS 2D SHADOWS